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ABSTRACT

The medical experiments approved for the AAP program (specifically the 56-day AAP 3, 4 flight) are summarized, emphasizing the astronaut time required for their performance. It is then shown how they could be performed more efficiently under four distinct sets of increasingly severe assumptions. The impact of the separate assumptions on the total medical experiment time is summarized, and it is concluded that (1) M018 (Vectorcardiogram) and M050 (Metabolic Costs of Inflight Tasks) involve enough common procedures and equipment to warrant the removal of almost the entire M018 experiment time from the program, (2) scheduling efficiencies can save about 7% of the total requested time, (3) if M050 could be converted to a one-man experiment, about 20% of the total requested two-man experiment time could be saved, and (4) if all of the efficiencies discussed here could be realized in practice, the total number of man-hours devoted to medical experiments would be reduced by a factor of two and the valuable two-man time would be reduced by 70% of the originally requested time. To develop a meaningful flight program, it is recommended that this type of analysis be performed on the ATM experiments and that both analyses be verified by ground-based trials.

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TECHNICAL MEMORANDUM

I. INTRODUCTION

In planning astronaut activities for specific missions, conflicts inevitably arise between scientific disciplines for experiment time. To create a meaningful flight program, the individual experiments must be made more efficient and the entire program must be integrated to eliminate duplicated measurements.

The Apollo Applications Program 3, 4 mission is a good example of such a conflict. Prior to the introduction of the 3a flight, the AAP 3, 4 mission included the first 56-day manned mission as well as the first flight of the Apollo Telescope Mount (ATM). Preliminary time-line analyses of this flight showed a strong competition between medical and ATM experiments, particularly for operations requiring two astronauts simultaneously.

This memorandum examines the medical experiments which have been assigned by the Apollo Applications Program Office to flights 3 and 4 from the point of view of increased time efficiency. The information for this analysis comes from two sources: (1) the most recent Experiment Implementation Plans (EIP), forms 1347, and their respective time-lines, dated variously from April to June, 1967; and (2) the AAP time-line presentation to C. W. Matthews by MSC and MSFC on November 1, 1967. For each experiment which is considered, its objectives, description and rationale, as stated in its EIP, are summarized, along with the astronaut time which it requires.

After discussing the individual experiments, we then carefully examine the astronaut time spent on medical experiments and show how the program might be made more efficient under four distinct assumptions of increasing severity: (a) the individual experiment could be made more efficient without compromising its objectives, (b) separate experiments could be combined into single operations without changing the information acquired, (c) parts of the proposed experiments could be eliminated with a large time savings but small information loss and (d) the experiments can be partially converted from two-man to one-man operations. The adequacy of each experiment in meeting its stated objectives is discussed, and some suggestions are made concerning medical questions not covered by the current set of experiments.

In order to show roughly how the assumptions a to d above affect astronaut experiment time, the total number of hours devoted to medical experiments for the entire mission is summarized in Table I for each experiment and each assumption. Although these numbers are useful as a first estimate of the impact of the various assumptions on the flight as a whole, they are not intended as strict guidelines for timeline analysis because the coordination of the medical experiments with each other and with the ATM experiments involves more than just total experiment time. Small blocks of time saved on individual experiments often cannot be used for any other useful purpose. Therefore, this memorandum represents only the first step in the integration of separate experiments into a meaningful flight program.

II. DISCUSSION OF INDIVIDUAL EXPERIMENTS AS CURRENTLY PROPOSED IN THE MOST RECENT EXPERIMENT IMPLEMENTATION PLANS

A. M018 Vectorcardiogram (VCG)

1. Objectives

The objective is to detect changes in electrical activity of the heart and changes in its position within the body wall as function of time under space flight conditions.

2. Rationale

Most of the degenerative changes which this important organ could undergo in the stress of space flight are immediately reflected in the VCG.

3. Description

VCG data will be recorded on three channels (+ voice channel) of the biomedical tape recorder before, during and after a 3-minute period of ergometer exercise. This is to be done daily on each astronaut or 40 times per subject during AAP 3, 4. Each test requires an observer and a subject and lasts 40 minutes. About ten minutes is needed to apply the electrodes and five minutes to remove them. For a total of 19 minutes during each measurement, the observer's only task is to make sure the data is being recorded properly.

4. Adequacy

The measurements are adequate to accomplish the experiment objectives, although for cleaner data interpretation (of the heart position) the PI would like to record respiration continuously.

B. M050 Metabolic Costs of Inflight Tasks

1. Objectives

Primary questions are: (1) is man's metabolic efficiency in doing mechanical work progressively altered in the space environment and (2) does the metabolic cost of doing a standard task depend upon the presence of gravity? Secondary objectives are (1) to evaluate ground-based reduced-gravity simulators, (2) to evaluate the bicycle ergometer as an exerciser for long-duration missions and (3) to determine the difference in metabolic cost of work between suited and non-suited work in a zero-g environment.

2. Rationale

In order to design life-support systems and plan logistic re-supply activities, it is necessary to know the net O_2 and food intake and the CO_2 and heat output of the astronaut during space flight activities. It is also important to know whether there are any metabolic limitations to the duration of manned missions. This information cannot be obtained from ground-based studies because zero-g conditions change the effort required to perform any task. In addition, the low ambient pressure of the spacecraft changes the work required to breathe.

3. Description

The astronaut's metabolic rate will be measured during rest, calibrated ergometer exercise and a standard task which is performed both in an inflated suit and unsuited. The following measurements are required during the tests: O_2 consumption, CO_2 production, heart rate, respiration rate and body temperature. In addition it is necessary to measure lung volumes periodically throughout the flight. The heart rate is to be measured with a simple set of electrodes involving one recording channel. Body temperature needs a second channel. The plan calls for the experiment to be performed four times for the 56-day AAP 3, 4 mission. Each experiment involves three runs: (A) ergometer exercise, (B) standard tasks, unsuited and (C) standard task in an inflated suit. According to the latest time summary available (June, 1967), runs A and B require 1.25 hours and run C requires 1.75 hours, the additional time being required for donning and doffing the suit.

Each run requires both the subject and an observer, but the PI states that it might be possible to eliminate the observer if the apparatus were carefully placed. However, assuming the observer is needed, the total time required for M050 during AAP 3, 4 is 51 hours of two-man experiment time.

4. Adequacy

In view of the complexity of energy exchange and storage mechanisms in warm blooded animals, it is desirable to have as many measures as possible of metabolic rate in order to understand how the human body functions in the space environment. The experiment as planned misses a good opportunity to measure the heat output of a man during a standardized task. This could be done by using the space suit as a calorimeter, i.e. by measuring the amount of cooling required to keep the temperature of the suit atmosphere constant while the task is being performed. This could probably be done automatically, eliminating any further demands on astronaut time. With the addition of this heat output measurement, the experiment would adequately accomplish its stated objectives.

C. M051 Inflight Assessment of Cardiovascular Function

1. Objectives

The objective is to evaluate the state of the cardiovascular system throughout the space flight. This involves the use of the Lower Body Negative Pressure test (LBNP) as an inflight analogue of the tilt table test of cardiovascular reflexes.

2. Rationale

The distribution of blood throughout the elastic vessels of the body is considerably altered in a weightless environment. As a result, the pressure regulating system, which ensures that the brain, muscles and digestive system receive the blood supply they need under varying conditions, must adapt to the weightless condition. It is essential to the health of the astronaut that we continuously monitor the ability of his cardiovascular system to withstand simulated 1-g conditions.

3. Description

Several cardiovascular parameters are to be measured in response to the application of negative pressure applied to the lower half of the body. (This distributes the blood preferentially to the legs in somewhat the same way that gravity would act when man assumes the upright position in a 1-g environment.) The parameters needed are blood pressure, heart rate (measured via ECG), respiration rate, leg volume and body temperature. This LBNP response is to be measured on each astronaut every three days inflight. Each experiment requires 70 minutes for both an observer and a subject. Assuming an experiment twice a week for the six weeks available for experiments in AAP 3, 4, the total experiment time required for M051 is 42 hours. It is required that the observer be a physician or physiologist with experience in cardiovascular physiology.

4. Adequacy

The measurements are sufficiently well planned to meet the experiment's objectives.

D. M053 Human Vestibular Function

1. Objectives

The objectives are to find out (1) whether or not the semi-circular canals change their sensitivity and (2) whether the astronaut's perception of space is altered when he is exposed to the zero-g environment for extended periods of time.

2. Rationale

The availability of a zero-g environment gives us the opportunity to assess the contribution of the gravity receptor (otolith) to our sense of spatial orientation, and to ascertain whether there are any interactions between our sense of angular acceleration (mediated by semi-circular canals) and gravity. This information cannot be obtained from ground-based studies. The subjective, unsystematic experience gained in the 14-day Gemini flight has indicated no spatial orientation problems, but longer missions might reveal some.

3. Description

The experiment consists of two parts: (1) evaluation of the sensitivity and susceptibility of the sense of angular acceleration and (2) tests of spatial localization using visual and proprioceptive (limb position) senses. In part (1a) the threshold for perception of angular acceleration is measured by decelerating a slowly rotating chair in which the blindfolded astronaut is sitting. As the deceleration is increased from zero, the subject reports the minimum amount which he can detect. This test requires nine minutes for a subject plus observer. Part (1b) involves tilting the subject's head while his chair rotates at gradually increasing speeds until the subject perceives the threshold of a slight malaise condition. This test requires 18 minutes for the subject plus observer.

Part (2a) tests for spatial localization with two measurements: (1) the visual adjustment of a line seen in special goggles to the perceived horizontal direction,* and (2) the manual placement of a pointer to the vertical axis of a hand-held sphere. These measurements are performed with the chair in an upright and in two tilt positions (forward and backward) and requires 43 minutes of experiment time. Part (2b) repeats the same measurements with the subject standing and requires 36 minutes. Part 1 is to be run sixteen times during the AAP 3, 4 mission for a total of 21.6 hours of two-man experiment time, and part 2 is to be run eight times inflight for a total of 31.6 hours.

4. Adequacy

The experiment as proposed is adequate to accomplish its stated objectives.

III. TIME EFFICIENCIES POSSIBLE UNDER A SET OF ASSUMPTIONS OF INCREASING SEVERITY

A. Individual Experiments Made More Efficient

1. M018 Vectorcardiogram

The efficiency of M018 can be improved by reducing the time required to attach and remove the electrodes each time the experiment is run. This can be done by either developing electrodes which remain intact for several days or by using electrodes which can be attached rapidly before each experiment.

2. M050 Metabolic Costs of Inflight Tasks

If the phases of this experiment were scheduled efficiently, some set-up and tear-down time would be saved. Consider one cycle of the experiment, where the three runs, (A), (B), and (C) are performed on each of the three astronauts. If a given day were devoted to a particular run, and the three subjects were tested consecutively, then the apparatus need only be set up and stowed away once, instead of three times. This would save about 20 minutes of experiment time for each A run and 43 minutes for the B and C runs.

The time-lines for runs B and C (standard task runs) show no entries for attaching any ECG electrodes. This may imply that the same subject, with his electrodes already attached, is to perform the 3 runs on the same day. Alternatively, it may imply that heart rate data are not needed for

* measured with respect to the floor of the habitable area in the S-IVB.

the standard tasks runs. Neither alternative is desirable in accomplishing the experiment objectives, since heart rate data is necessary for the experiment and the performance of standard tasks would be impaired by the exercise required in part A. In our analysis, we have included the time required to attach the ECG electrodes.

3. M051 Inflight Assessment of Cardiovascular Function

If the experiment were done on all three astronauts on the same day, two set up and two tear-down times would be eliminated. This would amount to about 20 minutes of experiment time saved for the day's run. It is impossible to eliminate the observer for this experiment.

4. M053 Human Vestibular Function

The set-up-time and take-down-time that would be saved by performing a given experiment on all three astronauts on the same day is as follows:

a. Part 1: 5 minutes for each experiment, or 1 hour and 20 minutes saved for AAP 3, 4 mission.

b. Part 2: no time can be saved.

B. Separate Experiments Combined

The entire set of vectorcardiogram measurements described in M018 are almost completely duplicated in M050 (Metabolic Costs on Inflight Tasks), providing the electrodes used for M050 are placed and connected according to the Frank lead system. This requires three channels of ECG data rather than the one channel originally required for M050. It should be pointed out that if M050 is modified as suggested here, six data channels will be needed -- three for ECG and one each for respiration rate, body temperature and voice. If an additional channel is used for time (a common requirement for FM tape recording), then all seven channels of the recorder are filled up. If this is unacceptable for some reason, then either an additional recorder is needed or M018 will have to be run separately or in combination with M051.

M018 could be combined with part A of M050, since the performance of the latter experiment is almost totally unaffected by the minor change in electrodes required. This would save 80 hours of two-man time from M018 and add about five minutes to each run of M050 part A. If ECG data are needed more often than the four times when part A is scheduled, they could be obtained when parts B and C are run. It must be emphasized, however, that at present parts B and C involve no ergometer exercise, as requested by M018.

It is possible to combine M018 with M051 (Cardiovascular Function) but the impact of this combination would be more severe to M051 than the change recommended above. If this were done, the experimental procedure of M051 would have to be modified to include a period of ergometer exercise, plus pre-and-post-exercise rest periods. Since the two stimuli (exercise and LBNP) would be applied consecutively, the second operation would be adversely affected by the first one.

Since part C of M050 involves performance of a standardized task while suited, it could be done at a time when EVA tasks are scheduled for any other purpose. If this were done, a separate operation of suit donning and doffing would be eliminated.

C. Elimination of Experiments With a Resulting Small Loss in Information

1. M050 Metabolic Costs of Inflight Tasks

No part of M050 could be eliminated without invalidating a major portion of the experiment.

2. M051 Inflight Assessment of Cardiovascular Function

Assuming that no cardiovascular troubles are found during and after AAP 1, 2, the frequency of M051 for AAP 3, 4 could be reduced from once every three days to once every six days at least during the first half of the mission. This would save about 10.5 hours of two-man time. The above comment is made only on the basis that LBNP is merely a test procedure, as implied by the PI. However, it could also be used on one or more of the astronauts as an experimental therapeutic device which helps maintain the integrity of the cardiovascular system during flight. In this therapeutic experiment, it would be logical to use the physician as the control subject (the one who is not tested), since he is required to be the observer for the other men. If the PI would permit a therapeutic LBNP session without measurements of the parameters needed for M051, then for the same 15-minute period of LBNP application, the time saved per experiment would be 28 minutes out of the 70-minute experiment. This time savings is not included in Table I.

3. M053 Human Vestibular Function

The frequency of part 1 could be reduced from 16 times during the AAP 3, 4 mission to eight times. This would be adequately frequent to meet the experiment objectives since it would then be performed just as often as part 2. (The PI does not indicate why part 1 should be run twice as often as part 2.). This would save 10.8 hours of 2-man experiment time during the AAP 3, 4 mission.

D. Conversion to One-Man Experiments

Before any experiment is attempted in flight, its feasibility for one-man operation must be thoroughly tested.

Using only the timelines from the corresponding EIP, we indicate here to what extent the experiments can be performed by one man.

1. M050 Metabolic Costs of Inflight Tasks

Part A: Ergometer Measurements

The observer can be eliminated if subject can:

a. reach EDS and ergometer controls from bicycle ergometer

b. check for mask leaks

c. apply VCG electrodes (from M018) to his own skin areas

d. verify proper recording while performing tasks (may be difficult during exercise for first few days of flight).

With these assumptions, time needed for one man is (1) 88.5 minutes to set up, run and take down the equipment for each test or (2) if part A is done on three astronauts on the same day, the one-man time needed for the day is 3.3 hours, or 13.3 hours for the AAP 3, 4 mission. However, since the subject may have difficulty placing the VCG electrodes on his back accurately, a helper will be needed for at least five minutes per experiment or one hour for the entire mission.

Part B: Unsuited Tasks

The one-man time needed for part B is: (1) 86 minutes to set up, run and take down the equipment for each test or (2) if part B is done on three subjects per day, the time needed per day is 4.75 hours or 19 hours for the mission.

Part C: Suited Tasks

The following comments apply only when EVA tasks are not scheduled with part C, as suggested on page 8.

1. The one-man time needed to set up the equipment, don suit, run the experiment, doff suit and take down the equipment is 3.1 hours.

2. If part C were run three times in one day, the total one-man time per day is 6.1 hours, or 24.4 hours for the mission.

It may not be possible at first for one man to do the tasks of M050 part B and C and monitor the instruments at the same time. Therefore, we should not plan to make this a one-man experiment from the beginning of the mission.

Since parts B and C involve the same tasks, it is possible to run both parts on the same astronaut on a given day. This would save the time required to disconnect body electrodes and take down the equipment between parts B and C for each astronaut. This scheduling would save more time than the alternate scheme of running each part on a given day for all three astronauts. However, we reject the first option because performing the same tasks repetitively would tire and bore the astronaut enough to invalidate the results of the second task.

2. M051 Inflight Assessment of Cardiovascular Function

This entire experiment can not be done by a single man because an observer (preferably a physician) must be present to check the subject's condition when negative pressure is applied. The observer is also needed to apply VCG electrodes to the subject's back and strain gauges to his legs, and to help establish a seal around his waist. It takes a single man forty minutes to set up and take down the equipment, and two men are needed for about fifty minutes in each experiment. This schedule would result in 24 hours of one-man time and 30 hours of two-man time for the AAP 3, 4 mission.

3. M053 Human Vestibular Function

The dynamic tests (part1) cannot be performed with one man. The static tests (part 2) could be performed with one man only if the data recording could be made automatic. But even then the man would have to obtain the sphere and put it away during the experiment without opening his eyes or getting any other clues of spatial locations. Since this would be difficult in principle, we would think at this time that the entire M053 experiment should be considered a two-man operation.

IV. ONE AREA NOT COVERED BY THE EXISTING MEDICAL PROGRAM

The effectiveness of the LBNP procedure as a therapeutic device to overcome the stresses of weightlessness could be evaluated by a slight variation of M051, as indicated on page 8. It is important to know early in the AAP program (preferably from experiments on AAP 1, 2 mission) whether a human centrifuge is needed for long-duration flight, since the hardware takes a long time to develop.

V. CONCLUSIONS

A. Table I shows that incorporation of M018 (Vectorcardiogram) into the M050 (Metabolic Costs) experiment and the accompanying reduction in frequency of VCG measurements will save about 35% of the total medical experiment time originally requested. In the absence of any justification by the PI of M018 for his request that it be done daily, and because of our intuition that any changes which might occur in heart function during space flight will develop slowly, this reduction of time devoted to M018 is not serious.

B. Adjusting the scheduling of existing experiments can save about 7% of the time originally requested.

C. Two-man time, which is at a premium, is reduced by over 40 hours, or about 20% of the originally requested time by converting all parts of M050 to a one-man experiment. At this time it is not certain that a single man can do parts B and C of the experiment at the beginning of the flight, but with experience, it might be feasible.

D. If all of the efficiencies here could be realized in practice, the total number of man-hours devoted to medical experiments would be reduced by a factor of two and valuable two-man time would be reduced by 70% of the originally requested time.

We have summarized the approved medical experiments for the AAP program, stating their objectives and rationale and emphasizing the time required for their performance. Using the most recent detailed time-lines from the Experiment Implementation Plans (forms 1347), we have then shown to what extent the experiments can be made more efficient in execution time. It is essential that any realistic evaluation of timelines be based on repeated walk-throughs to determine commonality of procedures and techniques. This type of analysis is essential to the planning of a successful flight program and should be done on the ATM experiments as well before detailed astronaut schedules are worked out for the AAP 3, 4 mission.

VI. ACKNOWLEDGMENT

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R. E. McGaughy

1011-REM-cb R. E. McGaughy

Attachment
Table I

TABLE I

SUMMARY OF TOTAL EXPERIMENT TIME FOR 56-DAY AAP 3, 4 MISSION

EXPERIMENT	REQUESTED TIME		TIME NEEDED AFTER STREAMLINING ASSUMPTIONS				
	NO. OF TIMES EXPT. IS REPEATED PER ASTRONAUT	TOTAL HOURS OF TWO-MAN TIME	IMPROVED EFFICIENCY	COMBINED EXPTS.	OMITTED EXPTS.	CONVERTED TO ONE-MAN OPERATIONS	
						ONE-MAN TIME	TWO-MAN TIME
M018	40	80	80[1]	0	0	0	0
M050	4	51	41.8[2]	42.8[3]	42.8	56.7[2]	3
M051	12	42	38	38	27.5(?)[4]	24[5]	30[5]
M053	Part 1 - 16 Part 2 - 8	53	51.7	51.7	43	0	35.2
TOTAL		226	211.5	132.5	113.3	80.7	68.2

[1]This time would be significantly reduced if "permanent" electrodes could be used. See page 6.

[2]Assuming that separate days are devoted to each part of M050 and that all three subjects do a given part on the same day.

[3]Assuming the VCG is done only with part A of M050. See page 7.

[4]Assuming that in the first half of the mission the frequency of M051 for each astronaut is reduced by one-half.

[5]Assuming that M051 is run the requested 12 times.